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DREDGING EFFICIENCY
AND
RE-SUSPENSION OF SEDIMENT

Prepared

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Report No. JBH-1981-28

October 1986

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INTRODUCTION

Polychlorinated biphenyls (PCBs) have been found in Waukegan Harbor and in the North Ditch/Parking Lot Area. Waukegan Harbor is an irregularly-shaped harbor (Figure 1) about 37 acres in area. According to Conceptual Design (EPA 13-5M28.0, September 14, 1984) the harbor has been divided into three general areas of PCB contamination:

a) Slip No. 3 - concentrations in excess of 500 parts per million (ppm),

b) the Upper Harbor - concentrations from 50 to 500 ppm, and

c) the Lower Harbor - concentrations from 10 to 50 ppm.

Water depths in the harbor generally vary from 14 to 25 (ft), with some shallower depths in parts of Slip No. 3. The extent of Federal Project dredging is shown in Figure 2.

The harbor sediments consist of 1 to 7 ft of very soft organic silt (muck) overlying typically 4 ft of medium dense, fine to coarse sand. A very stiff silt (glacial till) that typically ranges from 50 to more than 100 ft thick underlies the sand. The entire harbor is bordered by 20- to 25-ft long steel sheet piling. The sheet piles are believed to generally extend into the sand layer above the glacial till.

ALTERNATIVE DREDGING METHODS FOR REMOVAL OF PCBs

About twelve different types of dredging equipment were considered for the removal of sediment contaminated with PCBs from Slip No. 3 at the Waukegan Harbor. The most efficient equipment includes a cutterhead dredge, a plain suction dredge, a dustpan dredge and a Pneuma dredge. A clamshell

LOCATION	ESTIMATED CUBIC YARDS SEDIMENT	CALCULATED LBS. OF PCB
A1 TO A6	7,200 (MUCK)	167,000
NEAR OUTFALL	3,700 (SAND, CLAY & FILL)	138,000
B1 TO B5	38,000 (MUCK)	5,100
C1 TO C6	121,000 (MUCK)	2,300
D1 TO D3	18,000 (MUCK)	300

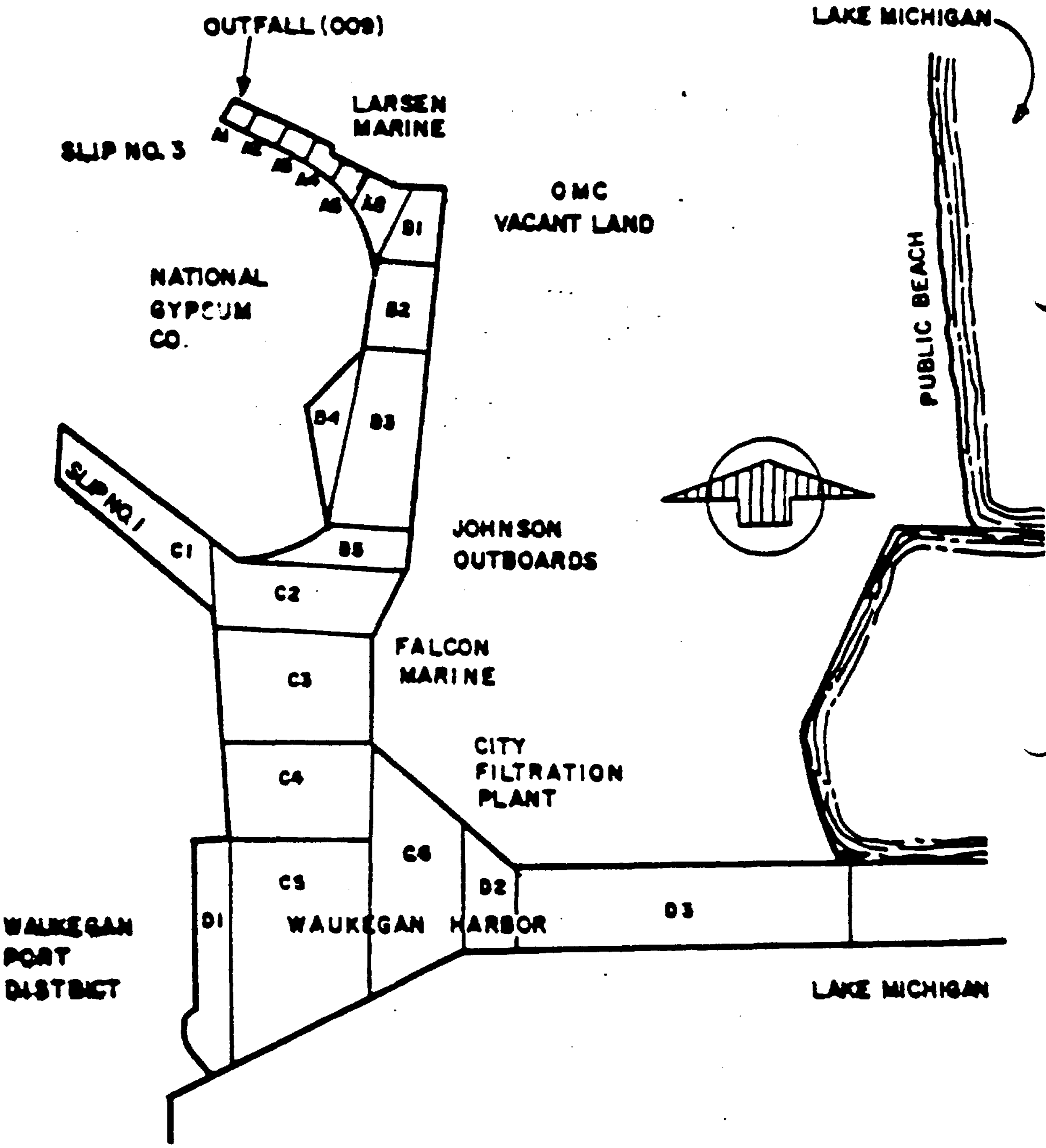


Figure 1. Extent of PCB contamination in sediment in Waukegan Harbor by amount (Revised March 31, 1982) (Reproduced from Protocol to Dredge, 5/23/1984).

CORPS OF ENGINEERS

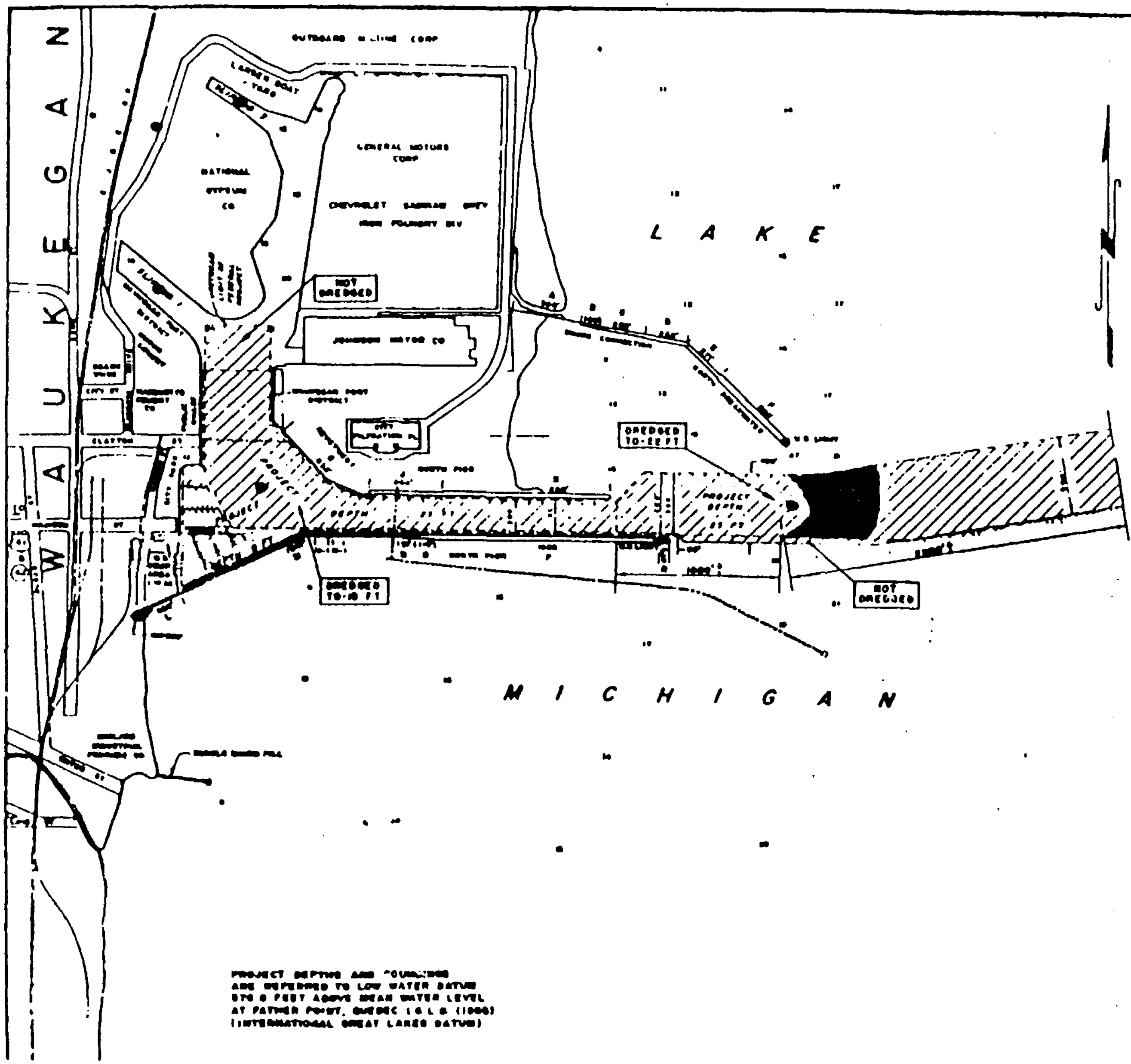


Figure 2. Extent of Federal Dredging Project.

dredge was also evaluated since it was specifically mentioned in the Conceptual Design report (p. 2-7).

1. CUTTERHEAD DREDGE

Principle of Operation

The cutterhead suction dredge is a very versatile and best-known dredging vessel. It differs from the dustpan dredge in that it is equipped with a rotating cutter apparatus surrounding the intake end of the suction pipe. Dredge pumps move the material loosened,or cut by the cutter,and discharge it through a pipeline at the disposal area.

Experience

The most commonly used type of dredge for construction of new channels or maintenance of existing channels and for general subaqueous excavation.

Turbidity

The turbidity of the water samples can be analyzed in terms of

a) suspended solids, in milligrams per liter,

b) Jackson turbidity units,

c) nephelometric turbidity units (NTU),

d) transmission, percent.

Huston (1976) conducted measurements of turbidity created by a cutterhead dredge. Table 1 indicates the turbidity readings in three different cutter speeds. Table 2 shows the background water data taken 1200 ft from the dredge. Table 3 compares the three turbidity unit measurements for background water 240 ft from dredge.

Huston concludes that the turbidity data shows several trends:

a) The transmission and scattering data in most cases show an increase in turbidity above background levels only in the immediate vicinity

Table 1

Turbidity at Different Cutter Speeds

CUT NO. 1 - 20 feet

Depth of Sample	10 rpm			20 rpm			30 rpm		
	%T	Mg/l	NTU	%T	Mg/l	NTU	%T	Mg/l	NTU
3	55	26	8	70	22	6	72	154	4
9	65	89	10	65	12	6	68	91	4
18	42	161	43	5	187	44	24	580	45

CUT NO. 2 - 30 feet

Depth of Sample	10 rpm			20 rpm			30 rpm		
	%T	Mg/l	NTU	%T	Mg/l	NTU	%T	Mg/l	NTU
3	47	114	3	56	-	7	66	106	4
10	41	64	9	45	46	7	65	80	5
20	44	102	15	38	-	8	50	11	15
30	17	55	14	5	37	37	4	208	26

CUT NO. 3 - 40 feet

Depth of Sample	10 rpm			20 rpm			30 rpm		
	%T	Mg/l	NTU	%T	Mg/l	NTU	%T	Mg/l	NTU
3	54	144	3	55	75	5	66	125	4
10	48	150	10	58	-	6	66	72	8
20	52	25	7	60	165	10	63	56	9
30	30	-	5	47	94	8	26	138	22
40	7	52	12	24	176	30	2	266	57

Table 2

Background Water Data

Depth Feet	Temp Deg C	Sal ppt	DO ppm	T %	Tide Knots	Tide Dir	pH
1	27.76	27.60	5.8	68			8.6
10	28.26	27.20	5.7	72	0.25	N90°E	8.6
20	27.00	28.20	5.7	64	0.25	N90°E	8.4
30	27.82	27.80	5.3	60	0.40	N90°E	8.0
40	27 80	27.60	4.2	46	0.40	N90°E	8.0

Wind = 18-20 knots Direction = N30°E Weather - fair, cldy

Sea state = 1 ft. Air Temp = 25.50C. Tide Hi: 0209; 1024
Lo: 0731; 1839

Time = 1130

Data taken 1200 feet easterly from dredge, in center of channel

Table 3

Comparison of Three Turbidity Unit Measurements for Background Water near Dredge

Depth of Sample (feet)	NTU	%T	Mg/l
3	6	72	94
10	8	71	77
20	8	69	168
30	4	65	39
40	9	50	50
45	14	44	209

Note: Samples taken in channel approximately 240 feet starboard of dredge of the cutter (the deepest measurement). The increased levels of turbidity around the cutter are probably due to the suspension of fine-grained material created by turbulence generated by the cutter.

b) In spite of turbidity generated by the cutter, the turbidity in the upper water column above the cutter (including all measurements except the deepest ones near the cutter) is usually comparable to those background levels measured 240 feet from the dredge. Reversals in turbidity readings in the upper part of the water column, similar to those reversals seen in the background data, are probably due to background variability. Apparently little of the turbidity created by the cutter went into the upper water column, especially from depths of 30 or 40 feet. This is also supported by the fact that no substantial visible surface turbidity was ever observed.

c) Although the turbidity data collected in the immediate vicinity of the cutter are quite variable, probably due to cutter-generated turbulence, there also may be a general, but inconsistent, increase in turbidity with increasing rpm. This inconsistency may be due to cutter-generated turbulence, variability in material being dredged, and/or suction velocity.

At other locations the re-suspended sediment concentrations varied from 158 mg/l (Upper Mississippi) to 303 mg/l (Cumberland River).

A relationship between suspended solids and relative production is shown in Figure 3.

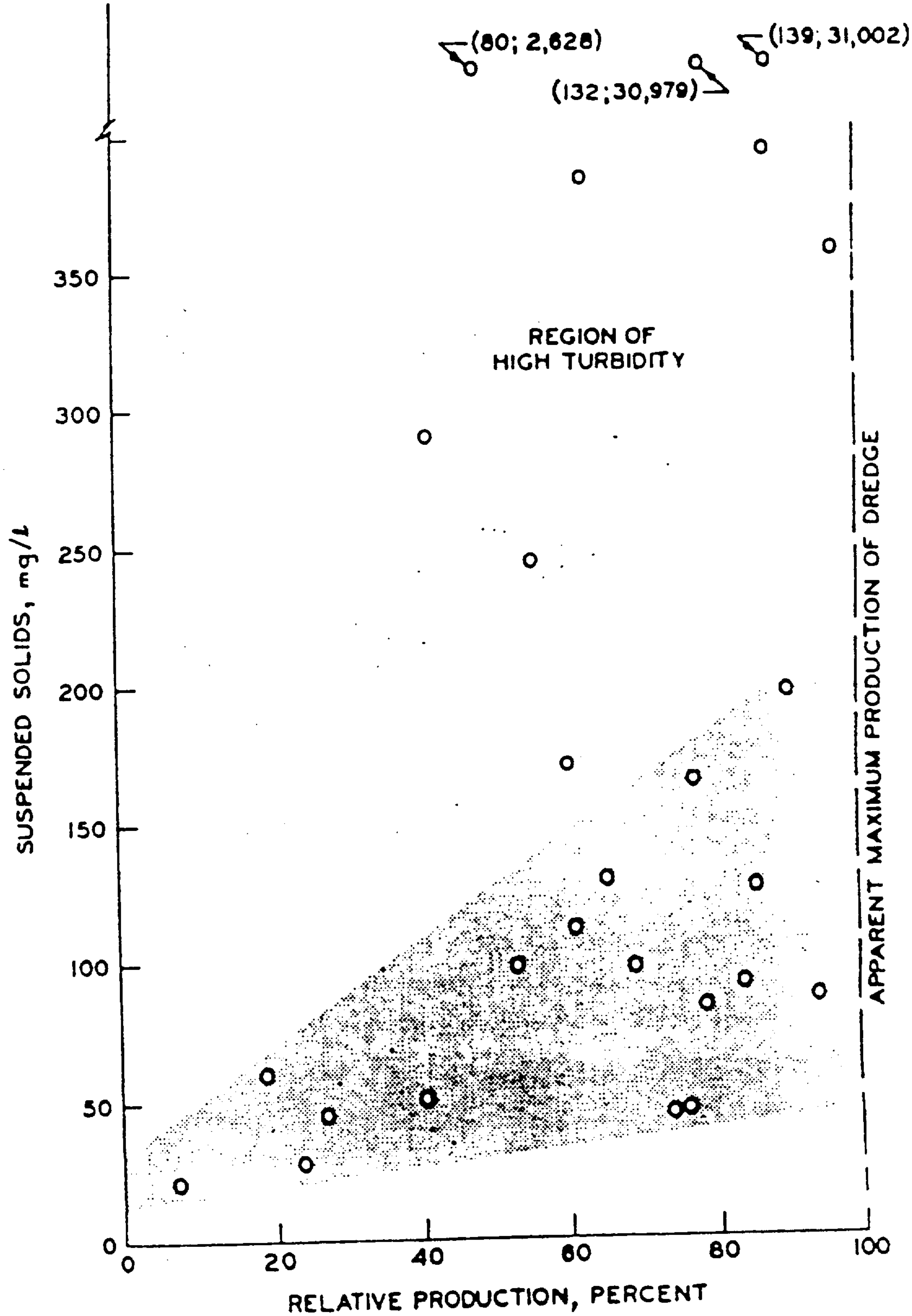


Figure 3. Relationship between the concentration of suspended solids 1 m from the cutter and the relative production of a 61-cm (24-in.) cutterhead dredge

2. PLAIN SUCTION DREDGE

Principle of Operation

The plain suction dredge is the simplest of the hydraulic suction dredges. It employs a long suction pipe to dig and lift the material to the surface. This dredge, however, works best in free flowing sand where gravity can feed the suction pipe. Digging may be supplemented by waterjets at the suction pipe mouth. Though these dredges can be used where they can remain stationary for long periods of time and are usually not self-propelled, they are designed to work in moderate swells and even in storm conditions. Individual dredges may be designed either to load their own hoppers, to load barges, or to pump through a pipeline.

Experience

This dredge is quite useful to beach nourishment programs. Though plain suction dredges possess offshore capabilities they are, however, suited for projects having free flowing, thick sand deposits.

Turbidity

Operating in free-flowing sand, a plain suction dredge usually causes little solids suspension. The use of water jets can create significant turbidity at the bottom. Turbidity at the surface can occur due to overflow of sediment-laden water from hoppers or barges. The turbidity generated by a plain suction dredge should be less than that caused by a cutterhead dredge because there is no rotating cutter.

3. DUSTPAN DREDGE

Principle of Operation

In the Dustpan dredge the suction head resembles a large vacuum cleaner or dustpan. The Dustpan dredge is a hydraulic, plain suction, self-propelled dredge. It consists essentially of a dredge pump which draws in a mixture of water and dredged materials through the suction head. The suction head is about as wide as the hull of the dredge and is fitted with high velocity water jets for agitating and mixing the material. The dredge can pump the slurried material to a disposal area. The Dustpan dredge is suitable only for high volume granular material.

Experience

Dustpan dredges have been developed and almost exclusively used in the United States. The Army Corps of Engineers has extensively used such dredges for deepening the Mississippi River. They are also being used in South America and Europe.

Turbidity

There is little turbidity for free-flowing sand but significant turbidity is expected at the bottom due to water jets.

4. GRAB/BUCKET/CLAMSHELL DREDGES

Principle of Operation

The grab, bucket, or clamshell dredge consists of a bucket or clamshell operated from a crane, or derrick mounted on a barge or on land. It is used extensively for removing relatively small volumes of material, particularly around docks, piers, or within restricted areas. The clamshell dredge usually leaves an irregular, cratered bottom.

Turbidity

The turbidity generated by a typical clamshell operation is high and can be traced to four major sources:

a. sediment resuspension occurring when the bucket impacts on and is pulled off the bottom.

b. the surface material in an open bucket is rapidly eroded as the bucket is pulled up through the water column.

c. further loss of sediment is experienced when the bucket breaks the water surface.

d. turbid water leaks through the openings between the jaws.

Field tests indicate the concentrations of re-suspended sediment in amounts varying from 30 to 500 milligrams/liter (mg/l). The following measurements were obtained and reported:

Location	Re-suspended Sediment
San Francisco	200 mg/l
Connecticut	168 mg/l
Maryland	30 mg/l
Japan	150-30 mg/l
Japan	500 mg/l (maximum)

5. WATERTIGHT CLAMSHELL

Principle of Operation

To minimize the turbidity generated by a typical clamshell operation, the Port and Harbor Institute, Japan, developed a watertight bucket that seals when the bucket is closed (Figure 4). In addition, the top of the watertight bucket is covered so that the dredged material is totally enclosed within the bucket.

Experience

According to the manufacturer these buckets are best adapted for dredging fine-grained, soft mud.

Turbidity

A direct comparison of a 1 cubic meter typical bucket with a watertight clamshell bucket indicates that watertight buckets generate 30 to 70% less turbidity in the water column than the typical buckets.

Measurements made 10 meters downstream from a 4 cubic meter watertight clamshell dredge excavating fine-grained material from a depth of 8 meters indicated that the maximum suspended solids concentrations were approximately 500 mg/l, or less throughout the water column relative to background levels of 50 mg/l or less. Near-bottom and mid water column suspended solids levels were greater than surface levels, indicating that resuspension of bottom material near the clamshell impact point is probably responsible for most of the material suspended in the lower portion of the water column.

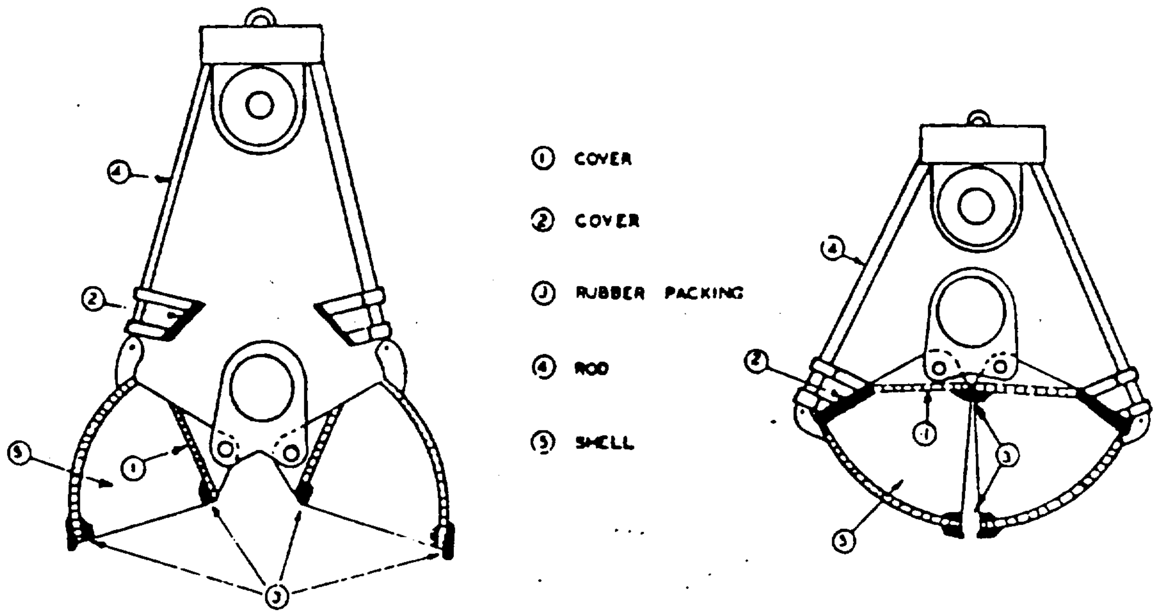


Figure 4. Open and closed positions of the watertight bucket

6. PNEUMA PUMP (Model 600/100)

Principle of Operation

The PNEUMA pump is a compressed-air-driven, displacement-type pump with several major components. The pump body (Figure 5), the largest of these components in dimensions and weight, incorporates three large cylindrical pressure vessels, each having a material intake on the bottom and an air port and discharge outlet on top. Each intake and discharge outlet is fitted with a check valve, allowing flow in one direction only. Pipes leading from the three discharge outlets join in a single discharge directly above the pressure vessels. Different types of attachments may be fitted on the intakes for removal of varying types of bottom material.

The operation principle of the pump body is illustrated in Figure 6. When dredging, the body is placed on the bottom with material intakes buried. Venting an air port to atmospheric pressure causes flow into a material intake driven by ambient water pressure. This continues until the pressure vessel is nearly full, at which time compressed air enters the pressure vessel through the air port. The compressed air forces material out of the pressure vessel through the discharge outlet and on to its final destination. The pressure vessels are operated so that filling/emptying cycles are out of phase but overlap enough to minimize discharge surging.

[1]"Pumping Performance and Turbidity Generation of Model 600/100 Pneuma Pump," by T.W. Richardson, et al., Technical Report No. HL-82-8, Prepared for Office, Chief of Engineers, U.S. Army, April 1982.

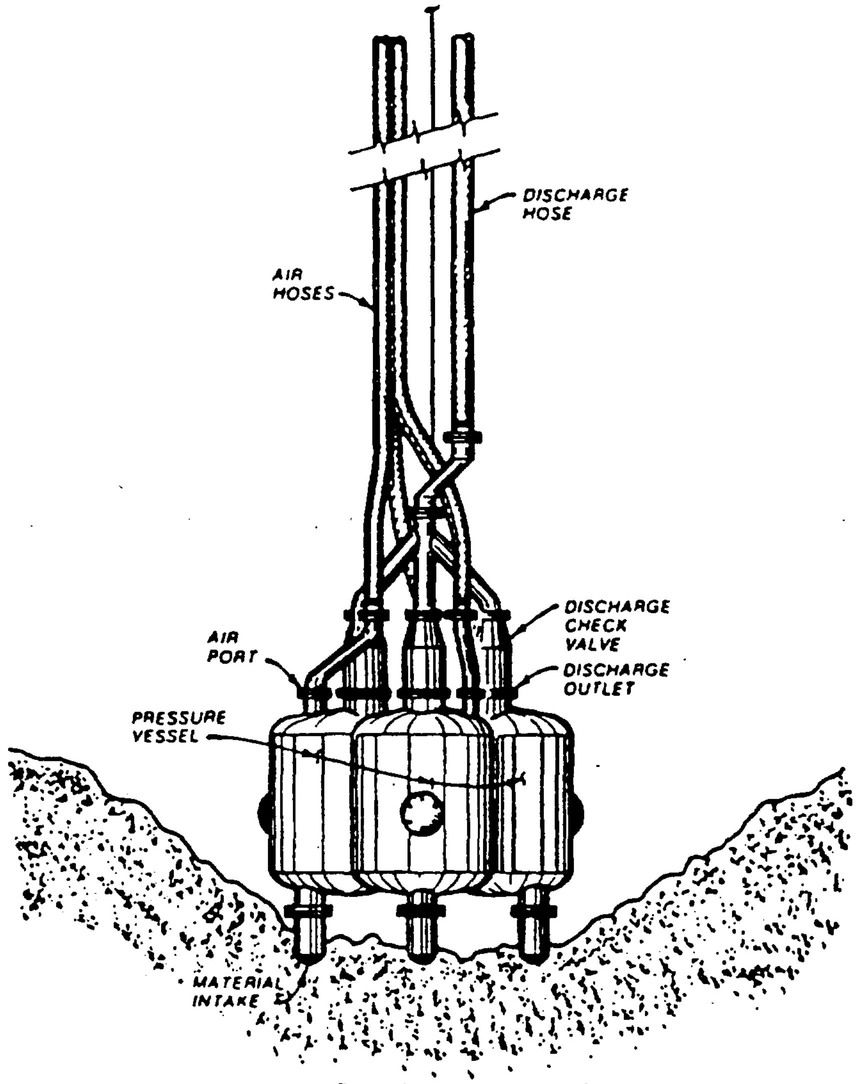


Figure 5. PNEUMA pump body

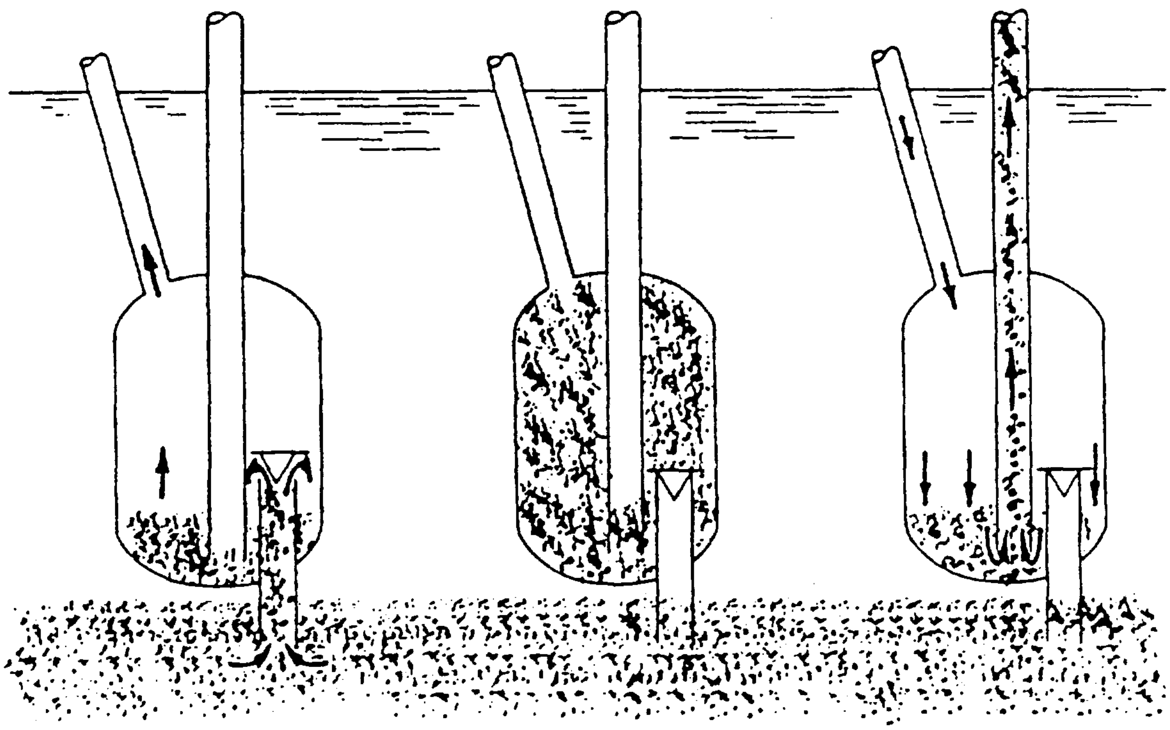


Figure 6. PNEUMA pump principle of operation

Timing and rate of pressure vessel cycles are controlled by an electrically driven air distributor (Figure 7). The heat of this device is a multi-ported spool valve rotated at a variable rate. Compressed air entering the valve is directed to a pressure vessel air port, while simultaneously another port is vented to the atmosphere. Variation of the valve rotational speed controls the pressure vessel cycle rate.

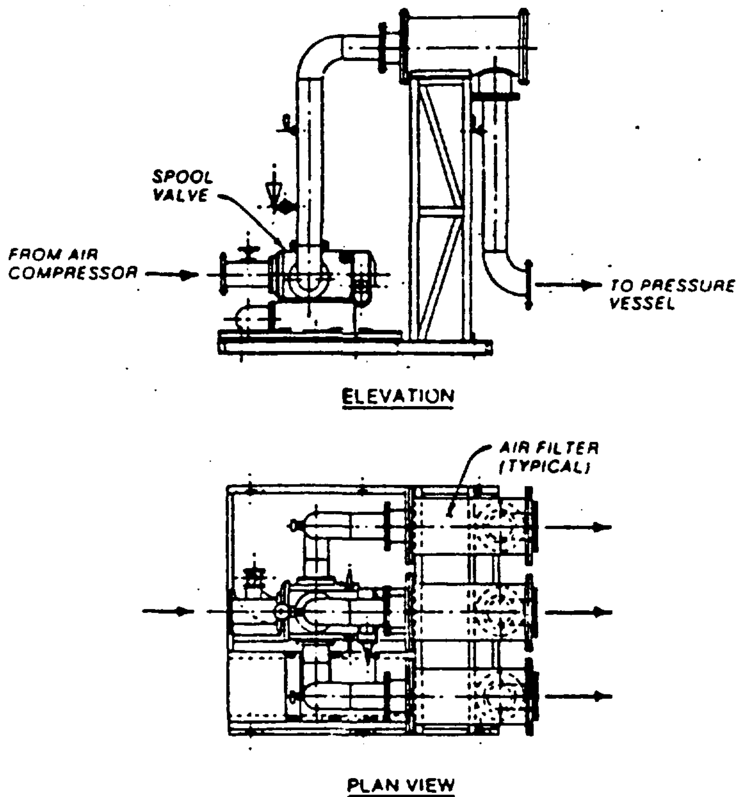


Figure 7. PNEUMA pump air distributor

The air distributor is connected to the pump body by three flexible hoses, each leading to a pressure vessel air port. A single flexible hose runs from the pump body discharge manifold back to the surface, where it connects to the surface discharge pipeline. The pump body and hoses are usually suspended by a harness from a crane or lifting frame, although other types of support are possible. Figure 8 shows a simple arrangement of all major pump components.

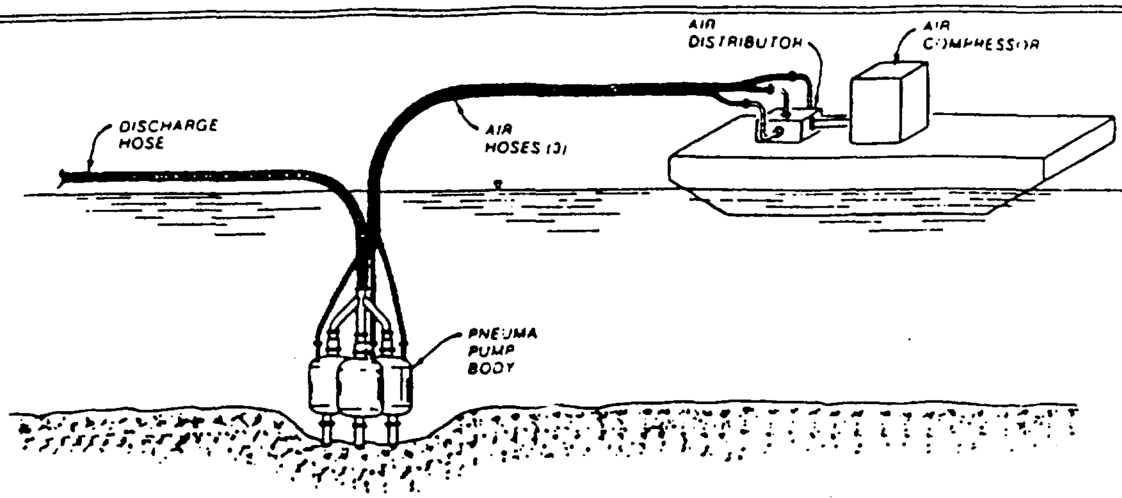
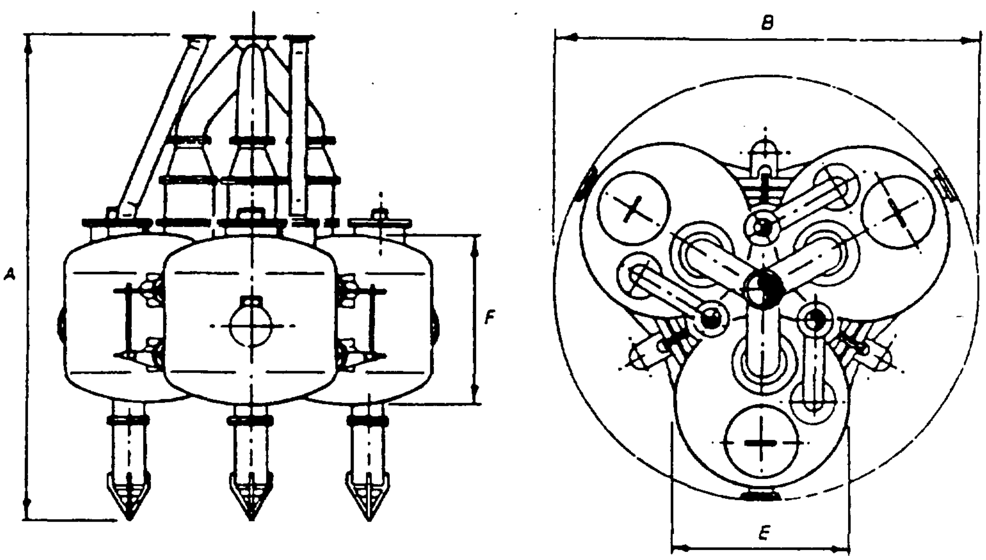


Figure 8. Major components of basic PNEUMA system

At the time of testing, the manufacturer produced six standard models of the PNEUMA pump. The pump tested was designated as Model 600/100. Figure 9 describes the pump body dimensions of standard models. Model 600/100 is one of the larger units, measuring 14.4 ft high by 12.2 ft in diameter and weighing 14,800 lb.



DIMENSIONS FT	150/30	300/60	450/80	600/100	1200/150	1500/200
A	12.0	13.4	14.4	14.4	18.7	20.3
B	8.6	10.2	12.2	12.2	15.1	15.1
C	10.5	12.1	13.4	13.8	18.7	20.3
D	9.8	10.8	13.3	13.3	15.9	16.1
E	3.3	3.9	4.9	4.9	5.9	5.9
F	3.9	4.9	4.9	6.8	8.2	9.8
WEIGHT (LB)	6620	9260	12570	14770	24920	28220

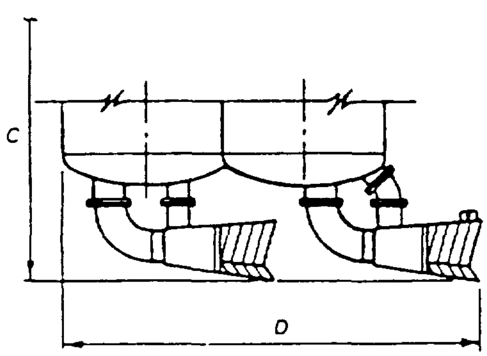


Figure 9. Pump body dimensions of standard PNEUMA models

Pump Efficiency

One of the characteristics of PNEUMA pumps is their inefficiency as a pumping device compared with a centrifugal pump. Pump efficiency is usually defined as the ratio of output to input horsepower. A well-designed centrifugal dredge pump can achieve 80 percent efficiency. By contrast the PNEUMA pump was found to have efficiency between 8 and 12 percent. However, PNEUMA pump can perform tasks not achievable by other pumps and is generally used for removal of small volumes of sediments.

Specific Gravity in the Discharge Line

The specific gravity in the discharge line of the pump varies cyclically due to the nature of the pump's operation. Consider the following:

> "The volume of a pressure vessel for a PNEUMA 600/100 pump is approximately 100 ft^3.* Assume that 75 percent of this volume, or 75 ft^3, is forced into the discharge line in each cycle at an average velocity of 10 fps. Then, in a 10-in. discharge pipe, it would take approximately 14 sec for the contents of one vessel to pass the nuclear density meter. Therefore, variations in pressure vessel contents would cause changes in discharge specific gravity at least every 14 sec."

The discharge may be described as "slug flow" and the density not only varies between slugs but also within each slug. Consequently the specific gravity in the discharge line while pumping sand was between 1.10 and 1.70. The specific gravities varied between 1.08 and 1.41 while pumping fine-grained sediments. The discharge densities of any significance could not be sustained longer than 15 minutes in either silty clay or sand.

Discharge Velocity

The discharge velocities varied from 6 to 8 feet per second for a 2000 ft long discharge pipe to 13 to 14 feet per second for pipe, to 420 ft long discharge line.

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*Source: conversation with PNEUMA North America.

Excavation Rate

Excavation rates in a location where the sediment was characterized as dark gray and black silty clay, in situ unit weight of 70.6 pounds per cubic foot was between 300 and 900 cubic yards per hour (median rate = 350 cubic yards per hour). This compares favorably with the median sand excavation rate of 185 cubic yards per hour.

Turbidity Generation

The turbidity generation monitoring program was not very successful since the PNEUMA pump was discharging water or extremely dilute sediment.

Sample results for excavating in dark gray and black silty clay are shown in Table 4.

Time from Start (min)	Distance from the Pump (ft)	Turbidity (NTU)*		Suspended Solids (mg/l)	
		Maximum	Average	Maximum	Average
10	25	6.0	6.65	4.05	7.89
20	25	17.5	17.75	6.90	6.20
30	25	20.5	16.50	5.35	5.19
40	100	21.0	14.13	6.35	6.02
50	100	40.0	48.25	21.50	15.88
60	100	60.0	19.50	26.40	9.79
70	100	14.0	21.38	7.40	16.60
80	100	14.0	9.50	6.75	6.01
90	100	16.0	8.75	6.70	5.65

*Nephelometric Turbidity Units (NTU)

TABLE 4. Measurements of turbidity generated by PNEUMA Pump.

Table 5 summarizes the approximate turbidity levels generated by different types of dredges.

Table 5. APPROXIMATE TURBIDITY LEVELS GENERATED BY DIFFERENT DREDGES

Type of Dredge	Turbidity	Remarks
1. Cutterhead		
10 RPM	161 mg/liter (sandy clay) 52 mg/liter (med. clay)	Observations in the Corpus Christi Channel
20 RPM	187 mg/liter (sandy clay) 177 mg/l (med. clay)	
30 RPM	580 mg/l (" ") 266 mg/l (" ")	
18 RPM	1 mg/l to 4 g/l within 3 m of cutter	Soft mud at Yokkaichi Harbor, Japan
18 RPM	2 mg/l to 31 g/l within 1 m of cutter	
2. Plain Suction Dredge	Little turbidity for free-flowing sand. Significant turbidity at the bottom with water jets.	
3. Dustpan Dredge	Little turbidity for free-flowing sand. Significant turbidity at the bottom created by water jets.	
4. Pneuma Pump	48 mg/l at 1 m above bottom	Port of Chofu, Japan
	4 mg/l at 7 m above bottom (5 m in front of pump)	
	13 mg/l at 1 m above bottom	Kita Kyushu City, Japan
5. Grab/Bucket/Clamshell Dredges	Less than 200 mg/l and average 30 to 90 mg/l at 50 m downstream (background level 40 mg/l)	San Francisco Bay
	168 mg/l near bottom 68 mg/l at surface	100 m downstream at lower Thames River, Connecticut
	150 mg/l to 300 mg/l at 3.5 m depth	Japanese observations
6. Anti-turbidity Watertight Buckets	30 to 70% less turbidity than typical buckets. 500 mg/l 10 m downstream from a 4 cu. m. watertight bucket.	Japan

ACCURACY OF THE DREDGING PROCESS

Dustpan Dredge

Vertical control: 1 ft

Horizontal control: 3 ft

Cutterhead Dredge

Vertical accuracy ±6-9 in. (protected waters)

Vertical accuracy ± 1 ft in sand and silty sand

Vertical accuracy ±1.5 ft in muck

Dipper Dredge

Quite accurate ±3 in.

Clamshell Dredge

Vertical accuracy ±9 in.

Note: Accuracy depends on the experience of the operator and on the type of soil. Also, on whether dredging is part of the maintenance work or new work.

SEDIMENT RE-SUSPENSION DURING DREDGING OPERATION

Other losses of sediment during the dredging operation include sediment re-suspension. The cutter of a cutterhead dredge re-suspends sediment thus creating a cloud which may not find its way into the suction pipe and may stay in the water column for a long time if composed of fine sediment. A clamshell impacts on the bottom sediments in order to pick up as much sediment as possible and it is then hoisted through the water column loosing as much as 30 to 50 percent of fine sediment. The watertight clamshell would loose about 35 percent less of sediment as it is hoisted through the water column.

Estimates of PCBs released during dredging operations are given in Table 6. The values of PCBs resuspended are shown in pounds for various locations indicated in Figure 1.

The highest weights of re-suspended PCBs are for the clamshell dredge and the lowest are for the Pneuma dredge.

TABLE 6. Estimates of PCB's released during dredging operations (values given in pounds)

SUMMARY

No.	Type of Dredge	Location A At 10 ft	A At 100 ft	B At 10 ft	B At 100 ft	C At 10 ft	C At 100 ft	D At 10 ft	D At 100 ft
1	Cutterhead Dredge* cutter speed 10 RPM	2,139	212	70.5	7.0	21.9	2.2	2.6	0.3
2	Cutterhead Dredge cutter speed 20 RPM	2,484	246	82	8.1	25.4	2.6	3.0	0.3
3	Cutterhead Dredge cutter speed 30 RPM	4,575	764	254	25.2	78.9	7.9	9.4	1.1
4	Plain Suction Dredge with water jets		comparable to cutterhead dredge (No. 1-3)						
5	Dustpan Dredge		comparable to cutterhead dredge (No. 1-3)						
6	Grab/Bucket/Clamshell	12,700		420		140		20	
7	Watertight Clamshell	3,810- -8,890		126- -294		42- -98		6- -14	
8	Pneuma Dredge (a) above the bottom (b) near the bottom	138 510		4.5 16.5		1.5 5.0		0.2 0.5	

*Based on 3 ft cutter and 2.5 cfs turbid flow.

DREDGING EFFICIENCY

Dredging efficiency depends on the type of dredge employed. The estimated cutterhead dredge efficiency in Slip No. 3 is 85.7% as the cutter will leave furrows in its path. The clamshell dredge (either open or closed bucket) is about 87% efficient. Pneuma dredge will also be about 87% efficient. The clamshell dredge will leave an irregular, cratered bottom and the Pneuma dredge will leave a cratered bottom.

PCBs left at the bottom of the harbor after dredging

1. Slip No. 3 - location A1-A6 (Figure 1)

Estimated volume of sediment: 7,200 cubic yards, mostly muck (Source: Protocol to dredge, 5/23/1984)

Calculated weight of PCBs: 167,000 lbs

Weight of PCBs left at the bottom after dredging:

a) cutterhead dredge: 23,881 lbs

b) clamshell dredge: 21,710 lbs

2. Near Outfall

Estimated volume of sediment: 3,700 cubic yards, sand clay and fill (Source: Protocol to dredge, 5/23/1984)

Calculated weight of PCBs: 138,000 lbs

Weight of PCBs left at the bottom after dredging:

a) cutterhead dredge: 19,734 lbs

b) clamshell dredge: 17,940 lbs

Note: Pneuma dredge and a watertight clamshell dredge will leave the same amounts of PCBs as the clamshell dredge.

OTHER LOSSES OF SEDIMENT AND WATER CONTAINING PCBs

In addition to re-suspension of sediment by the dredging process, other losses occur that are caused by leaks at the pump-pipe connections, at the pump seals, at the pipe joints, ball joints, etc. Some water and sediments containing PCBs could be lost along the discharge pipeline, or at the pump located on the dredge. Some contaminated water could escape during de-contamination of equipment used such as pipes, pumps, valves, clamshells, etc. Evaporation of water will occur during the dredging process, at the treatment plant, during trucking operations, and from the surface of disposal lagoons.

CONCLUSIONS

1. Several types of dredges were considered for removal of bottom sediments from Slip No. 3; the most suitable dredging plants include a cutterhead dredge and a Pneuma dredge. A clamshell dredge is recommended in "Conceptual Design" Report EPA 13-5M28.0.
2. Sediment removal efficiency is estimated to be 85.7% for the cutterhead dredge and 87.0% for both Pneuma dredge and the clamshell dredge.
3. Weight of PCBs left in Slip No. 3 after dredging is estimated to be 23,881 lbs for the cutterhead dredge and 21,710 lbs for the clamshell and Pneuma dredge.
4. Weight of PCBs left in an area near the outfall after dredging is estimated to be 19,734 lbs for the cutterhead dredge and 17,940 lbs for the clamshell and Pneuma dredge.
5. The concentration of PCBs will be much greater at the bottom after dredging than it is at present since fine silt has covered the bottom in recent years. The fine sediment deposition, in effect, has capped the contaminated sediment.
6. PCBs will be re-suspended in the water column by the dredging process. It is estimated that at least 2,139 lbs of PCBs will be re-suspended by the cutterhead dredge and about 12,700 lbs of PCBs by the clamshell dredge.
7. Additional sediment losses will occur during the dredging process because of leaks in pumps, pipeline joints, etc.
8. The fine re-suspended sediment will take a long time to settle in Slip No. 3. Calculations based on the sediment samples taken indicate that 63% of solids will settle in about 40 days, and that 77% of solids will settle in about 4160 days. Wind-generated currents will keep the solids suspended for indefinite periods of time.

DREDGING EFFICIENCY

Dredging efficiency depends on the type of dredge employed. The estimated cutterhead dredge efficiency in Slip No. 3 is 85.7% as the cutter will leave furrows in its path. The clamshell dredge (either open or closed bucket) is about 87% efficient. Pneuma dredge will also be about 87% efficient. The clamshell dredge will leave an irregular, cratered bottom and the Pneuma dredge will leave a cratered bottom.

PCBs left at the bottom of the harbor after dredging

1. Slip No. 3 - location A1-A6 (Figure 1)

Estimated volume of sediment: 7,200 cubic yards, mostly muck (Source: Protocol to dredge, 5/23/1984)

Calculated weight of PCBs: 167,000 lbs

Weight of PCBs left at the bottom after dredging:

a) cutterhead dredge: 23,881 lbs

b) clamshell dredge: 21,710 lbs

2. Near Outfall

Estimated volume of sediment: 3,700 cubic yards, sand clay and fill (Source: Protocol to dredge, 5/23/1984)

Calculated weight of PCBs: 138,000 lbs

Weight of PCBs left at the bottom after dredging:

a) cutterhead dredge: 19,734 lbs

b) clamshell dredge: 17,940 lbs

Note: Pneuma dredge and a watertight clamshell dredge will leave the same amounts of PCBs as the clamshell dredge.

Clamshell bucket

Characteristics:

- mechanical dredge, clamshell dropped, closed and lifted to remove sediment from the bottom;
- most turbidity generated when bucket impacts on the bottom and is pulled off the bottom; the surface material in the bucket, and the material adhering to the outside is exposed to the water column during pull up, is released to the water column.

Field tests:

Location	Resuspended sediment
San Francisco	200 mg/l
Connecticut	168 mg/l
Maryland	30 mg/l
Japan	150-300 mg/l
	500 mg/l maximum

Efficiency of operation: 87%

Reprinted from the Proceedings of the Conference Dredging '84 Waterway, Port, Coastal and Ocean Division, ASCE/Nov. 14-16, 1984, Clearwater Beach, Florida

TURBIDITY GENERATED BY A MODEL CUTTERHEAD DREDGE

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ABSTRACT

A turbidity cloud is generated by the cutter which is mounted on the ladder of a cutterhead dredge. The magnitude of the turbidity depends on the cutter rotation and the efficiency of the hydraulic suction system. The resuspension of the bottom sediments containing toxic substances depends to a large extent on the turbidity generated by the cutterhead dredge.

There has been a need to study the complex nature of flow around the cutterhead, leading to a better understanding of the various factors contributing to turbidity generation. This in turn will lead to improved design of the cutterhead systems, including turbidity shields, which will substantially reduce resuspension of bottom sediments containing toxic substances.

The study of turbidity generation indicates that, in general, turbidity increases with an increase in the cutter speed and an increase in the cutter swing velocity. A silt curtain deployed in front of the cutter was found to be very effective in reducing turbidity. Since the turbidity cloud is trapped by the curtain and reflected towards the cutterhead, an increase in pumping efficiency can also be expected.

INTRODUCTION

Dredging has become more challenging than ever in view of complex projects such as the deepening of ports and harbors with depths more than 55 ft (16.8 m), offshore dredging for mining purposes, beach replenishment, etc. Many environmental rules and regulations have added a new dimension to the complexity of dredging projects. In the United States, the U.S. Army Corps of Engineers is responsible for the development and maintenance of navigable waterways and ship channels, and an increasingly larger portion of dredging is conducted by private industry under contract with the Corps. A large volume of dredging is performed by cutterhead hydraulic dredges.

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similar to Froude number (where u_1 = swing velocity of cutter, d = pipe diameter, d_s = diameter of sediment, C = sediment concentration, ν = kinematic velocity, ω = rotational velocity of cutter, D = cutter diameter, and g = acceleration due to gravity).

The plot of $\frac{u_1 d^2}{d_s C \nu}$ (Reynolds Number) against $\frac{R_1}{D}$ is presented in Figure 2 and the plot for $\frac{\omega DV}{d_s gC}$ is presented in Figure 3 (where V = pipe velocity at intake). No relationship could be detected from these dimensionless groups. A combination of the two dimensionless products $\frac{\omega DV}{d_s gC}$ and $\frac{u_1 d^2}{d_s C \nu}$ was also examined but no apparent relationship existed. It was seen that all data points obtained from model test results were found to lie on one line in the plot of $\frac{R_1}{D}$ versus the ratio of $\frac{u_1 d^2}{d_s C \nu}$ and $\frac{\omega DV}{d_s gC}$. However, the point representing the prototype was off the line by a wide margin (Figure 4). It was clear that the available information on the prototype data was incomplete and not quite adequate for complete analysis. Since the model turbidity values compared with prototype measurements on the basis of Froude relationship were very high, it was concluded that turbidity generation at the cutter does not follow the similitude relationship based on the Froude criterion.

Figure 5 shows a plot of turbidity in front of cutterhead in grams per liter against the Reynolds' number. It was concluded that the Reynolds' criterion was perhaps the closest to provide any similitude relationship among the variables. Since the prototype data were insufficient, no exact relationship can, at present, be established.

CONCLUSIONS

1. Turbidity at the cutterhead was found to move horizontally in all directions but very little in the vertical direction. The major portion of turbidity in the model was found within a small distance above the bottom. The scraping of material on the rear side and the clockwise rotational movement of the cutterhead lifted the material a little on the sides which then moved forward. The studies did not provide any indication on how the basket-type cutters used in the studies helped in guiding the material towards the intake. The studies, however, showed there was considerable churning action at the bottom resulting in resuspension of bottom sediment. The suction discharge picked up suspended sediment from within the zone of influence of the suction pipe. The remaining suspended material rapidly moved into the adjoining areas.

2. Model studies on turbidity generation at the cutterhead indicated an increase in turbidity with increase in the cutter speed and swing velocity. The contribution of the swinging action of the cutterheads to the total turbidity generated at the cutterhead was found to be in the region of 20 to 30 percent of the total value.

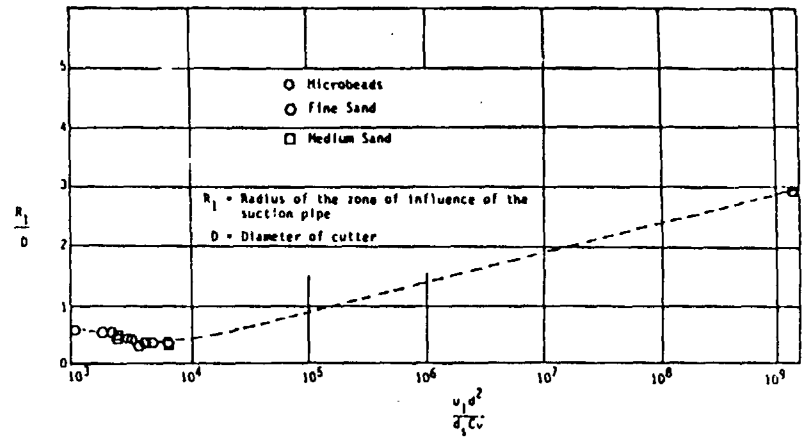

Figure 2. Plot of $\frac{u_1 d^2}{d_s C \nu}$ (Reynolds' Number) versus $\frac{R_1}{D}$ for all materials employed in the study

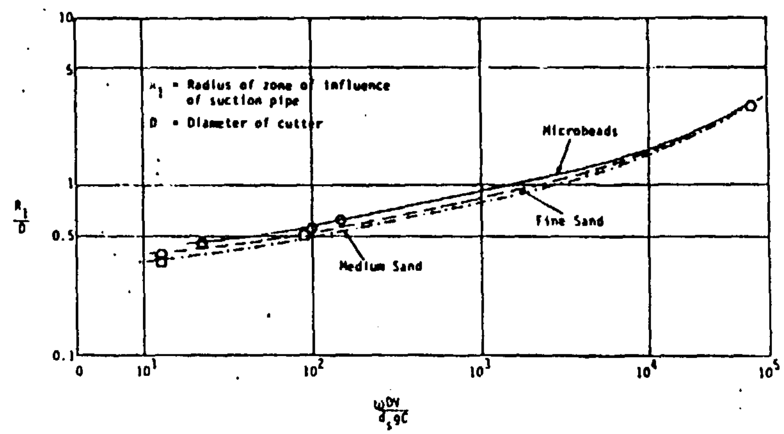

Figure 3. Plot of $\frac{\omega DV}{d_s gC}$ (Froude Number) versus $\frac{R_1}{D}$ for all materials employed in the study

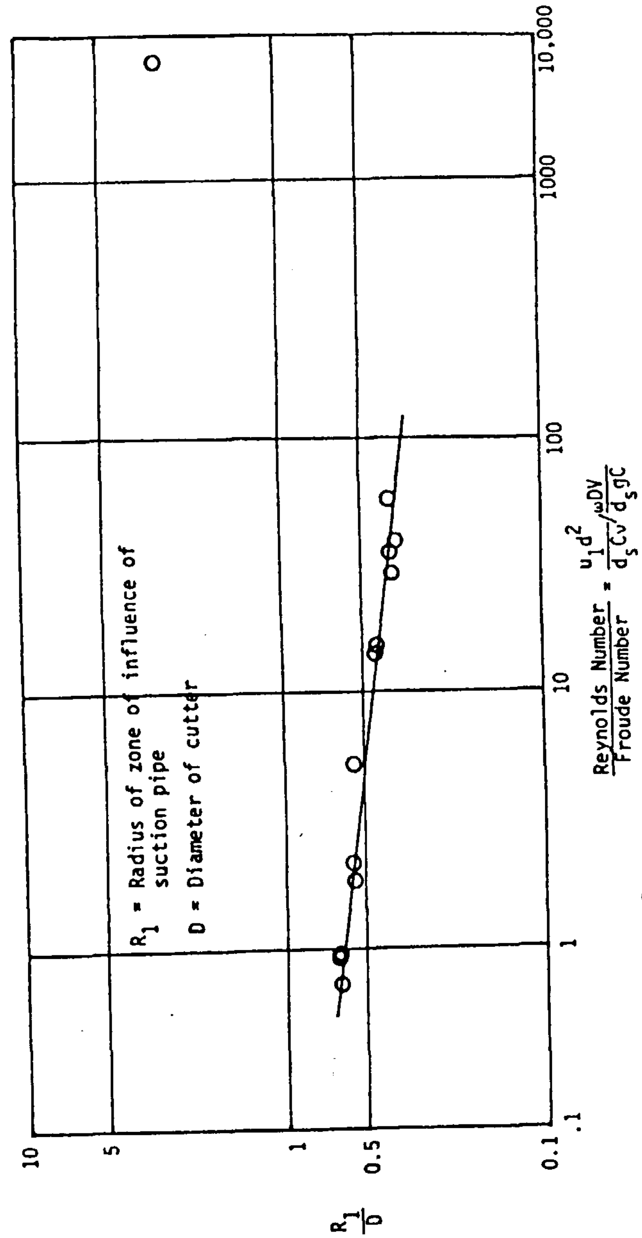

Figure 4. Plot of $\frac{R_1}{D}$ versus ratio of Reynolds' and Froude Numbers

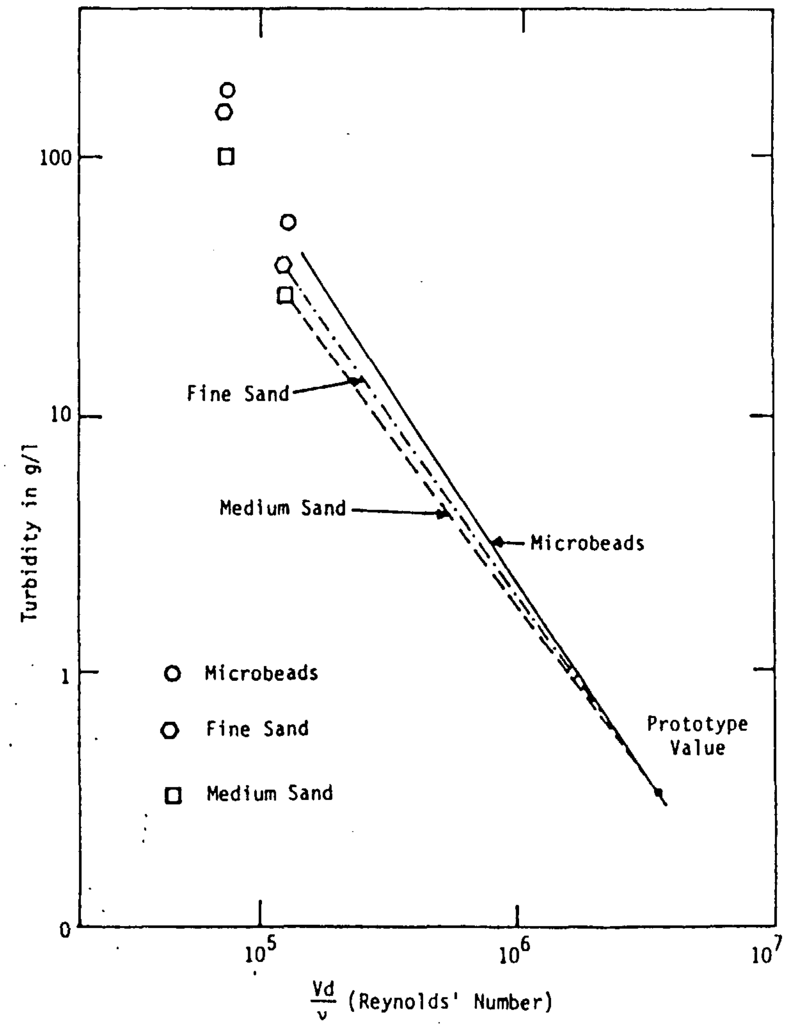

Figure 5. Plot of turbidity in g/l versus Reynolds' Number of different materials

3. Turbidity generation phenomenon more closely relates to the Reynolds' type of similitude relationship.

4. Silt curtains used in the model clearly indicated that it is possible to confine the spread of turbidity to a small area near the cutter and reduce the turbidity generated by a cutterhead dredge.

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